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Bart C. H. de Zwart · Monique H. W. Frings-Dresen
Frank J. H. van Dijk

Physical workload and the ageing worker: a review of the literature

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Abstract In the coming decades, demographic, economic and social changes will result in an increased proportion of elderly persons in the workforce in most industrialized countries. This trend is causing growing interest in the problems of the ageing worker in current employment. The objective of this particular paper is to provide more insight into the impact of ageing on the balance between physical work capacity and physical workload. To this end, the scientific literature in the field is reviewed and ordered by means of a specific conceptual model of "ageing and physical workload". A progressive decline in physical work capacity, characterized by diminished aerobic capacity and muscular capacity, has consistently been reported. However, inter-individual differences appear to be considerable. The question of whether there are systematic differences in physical work demands between younger and older workers within occupations has been answered vaguely. Conflicting results in this matter bring into discussion the role of the actual working method as one of the determinants of the physical workload. An age-related imbalance between physical workload and physical work capacity is suggested to result in a chronic overload, increasing the risk of long-term health effects such as musculoskeletal complaints and disorders. For many ageing workers in physically demanding occupations, extreme physical workloads, increasing the risk of disease or disablement, are still reported. The multiconceptual study of ageing and physical workload in the present paper reveals several possibilities for preventive measures. However, as information is still lacking, additional research is needed, in particular on the onset and development of long-term effects on health in relation to age and work demands.

Key words Ageing · Physical work capacity · Physical work demands · Actual working method · Physical workload · Long-term physical health effects

B. C. H. de Zwart (✉) · M. H. W. Frings-Dresen · F. J. H. van Dijk
Study Centre on Work and Health/Coronel Laboratory, Academic Medical Centre, University of Amsterdam, Meibergdreef 15, 1105 AZ Amsterdam, The Netherlands

Introduction

Over recent years, the study of ageing and work has attracted growing attention in scientific literature as a direct consequence of demographic changes in the age structure of the workforce in many industrialized countries [41, 100]. For example, the proportion of workers between 45 and 64 years among the population of active age is expected to rise from 32.1% in 1990 to 42.3% in 2020. By contrast, the proportion of the youngest workers, 15–24 years, is expected to decrease from 23.1% in 1990 to 18.4% in 2020 [76].

In particular, there is growing interest in the impact of ageing on the balance between physical workload and physical work capacity. Negative consequences for health and well-being may be expected when an age-related imbalance between these two factors appears [54]. An increase in prevalence rates of physical complaints and disorders with advancing age has frequently been revealed in studies of physically demanding occupations [28, 105, 108, 111]. These complaints may reduce individual work capacity to a level which prevents the continuation of work as a result of disease or disablement.

The objective of the present review is to provide greater insight into the consequences of ageing for the balance between physical workload and physical work capacity. Knowledge of the mechanisms concerned will provide a firmer base for the development and implementation of preventive measures for the ageing worker in physically demanding occupations. To this end, studies in this field are reviewed and ordered by

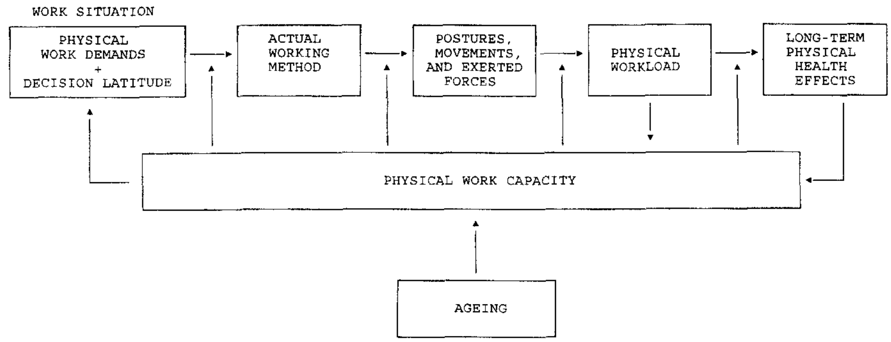

Fig. 1 The model of "ageing and physical workload"

Table 1 Definition of concepts used in the model of "ageing and physical workload"

Physical work capacity: physical capacities and characteristics of a worker. Physical work capacity is a dynamic measure. Changes may occur in a short-term period, such as changes over the day caused by fatigue, as well as in long-term periods, such as increase or decrease in muscle strength in months or years.

Work situation:
a) *Physical work demands*: physical-loading factors in the work situation responsible for physical responses, such as muscular work, climate and vibration
b) *Decision latitude*: extent of autonomy and possibilities for the worker to improve, or to worsen, the working situation by means of altering the work demands.

Actual working method: the way the work is done, characterized by, for example, work rate, utilization of (mechanical) devices, lifting technique, number of breaks.

Working postures, movements and exerted forces: the sequence of body postures, movements and exerted forces on the environment during work.

Physical workload: all temporary short-term physical responses which can be regarded as indicators of the physical workload – changes in, for example, heart rate, breathing frequency, hormonal responses, and blood pressure, but also sweating and feelings of fatigue, during work and some hours thereafter.

Long-term physical health effects: all more chronic, recurrent or permanent physical effects of physical workload on health, both positive and negative.

Ageing:
The concept of ageing in this paper can be described as the sum of the changes in structure and function of an organism that occur with the passage of time. Three determinants of ageing can be distinguished, showing a mutual interaction.
a) *Biological ageing*: gradual specific changes in the structure of an organism with increasing age that do not result from disease or accidents.
b) *Diseases*: condition which alters or interferes with the normal state of an organism, usually characterized by abnormal functioning of one or more of the host's systems, parts or organs. Often manifested by a characteristic set of signs and symptoms.
c) *Life-style*: the way in which an individual lives, expressed by, for example, the level of physical activity, eating, drinking and smoking habits.

means of a specific conceptual model entitled "ageing and physical workload".

Model of ageing and physical workload

The various concepts involved in the study of ageing and physical workload are presented in the aforementioned specific conceptual model in Fig. 1 and Table 1. This approach is based on the dynamic model of "workload" proposed by Van Dijk et al. [113, see also 80, 112, 114]. In this paper, the model of "ageing and physical workload" is used as a conceptual framework for the arrangement of the basic concepts presented in the literature, and for description and analyses of the hypothetical relations between these concepts. Moreover, the model may identify needs and opportunities for research. An additional advantage of this model is the opportunity to present all kinds of measurement and intervention strategies.

Physical work capacity occupies a prominent place in the model. Three age-contingent determinants affecting physical work capacity can be distinguished: physical workload, long-term physical health effects and ageing itself.

The work situation is characterized by the physical work demands including tools and equipment and the worker's decision latitude permitted in the work situation. The actual working method is determined by the interaction between the demands of the working situation and the individual physical work capacity, such as physiological capacities and physical skills learned by experience. An interaction between the actual working method applied and the physical work capacity, such as body dimension and strength, results in a sequence of specific working postures, movements and exerted forces by the worker. Further, the physical workload depends on the interaction between the sum of the working postures, movements and exerted forces and the physical work capacity. The evoked physical short-term responses can be regarded as indicators of the individual physical workload. The workload expressed as a percentage of the maximal capacity, the relative workload [9], gives a rough indication of the balance between these two factors and the reserve capacity available. A relatively high workload can result in insufficient recovery after daily work, inducing adverse long-term physical health effects such as chronic fatigue or musculoskeletal complaints. These effects can affect the worker's physical work capacity in a negative way. In the upper left part of the model the possibility is shown that a reduced physical work capacity, as a result of biological ageing, diseases or deconditioning, may be a reason for the employer or employee to eliminate physical demanding tasks within a working situation. The concept of ageing itself is pictured in the lower part of the model, characterized by the sum of the changes in structure and function of an organism with advancing age, resulting among other things in an age-related change in physical work capacity. Biological ageing, diseases and life-style may be regarded as determinants of ageing, showing a mutual interaction.

In recent years, several recommendable studies have addressed the relation between psychosocial factors at work and physical disorders such as musculoskeletal disorders [17, 47]. We are aware of the fact that, for the ageing worker in physically demanding occupations, too, the effects of psychosocial factors at work on the onset of physical disorders should not be underestimated. However, in order to present a compact and conveniently arranged paper, the relation between ageing and psychosocial factors at work is not included in this review.

With this in mind, a critical analysis and ordering of the literature may be helpful in elucidating the impact of ageing on the balance between physical workload and physical work capacity.

Physical work capacity and ageing

For several decades, a large number of scientists have been fascinated by the impact of age upon physical work capacity [5, 13, 16, 23, 38, 63, 70, 77, 79, 95, 98]. Physical work capacity may be characterized by the sum of the physical capacities and characteristics. Two relevant aspects in this matter are the aerobic capacity and the muscular capacity. The development of these capacities from childhood until old age has been the subject of numerous studies. As this paper concentrates on the ageing worker, emphasis will be placed on research data describing changes between the boundaries of 20 and 65 years only.

Aerobic capacity

Aerobic capacity may be defined as the ability of the cardiorespiratory system to deliver oxygenated blood to metabolizing tissues and the ability of these structures to extract oxygen from the delivered blood [31]. Over recent decades, maximal oxygen consumption ($\dot{V}O_{2max}$), the highest oxygen uptake the individual can attain during exercise and the product of cardiac output and systemic arteriovenous oxygen difference, has been considered to be a valid measure of overall aerobic capacity [104]. Moreover, $\dot{V}O_{2max}$ is regarded as the best single variable to define age-dependent changes in functional limits of aerobic metabolism and of the cardiorespiratory system [19].

The first cross-sectional comparison of $\dot{V}O_{2max}$ over different age classes was made by Robinson [90]. In his classic investigation, evidence was found for a progressive decline in aerobic capacity with ageing. Since then, a linear decline of $\dot{V}O_{2max}$ after the age of 20–25 years for both males and females has clearly been established in numerous cross-sectional and longitudinal studies [5, 12, 21, 78, 86, 91–93, 119; see also Table 2].

In cross-sectional studies the reported decline has varied from 0.25 to 0.80 $ml \cdot kg^{-1} \cdot min^{-1} \cdot year^{-1}$ for men and from 0.25 to 0.40 $ml \cdot kg^{-1} \cdot min^{-1} \cdot year^{-1}$ for women. Longitudinal studies on the rate of decline of aerobic capacity with ageing, varying from 2.3 to 21 follow-up years, have tended to indicate higher values than those reported in cross-sectional studies. In men, a range in decline from 0.56 to an extreme value of 1.62 $ml \cdot kg^{-1} \cdot min^{-1} \cdot year^{-1}$ ($n = 8$) has been found, whereas for women declines of between 0.32 and 0.58 $ml \cdot kg^{-1} \cdot min^{-1} \cdot year^{-1}$ have been reported. A majority of the cross-sectional and longitudinal studies have demonstrated a lower absolute rate of decline in $\dot{V}O_{2max}$ with advancing age in women than in men.

In general, large inter-study variation can be attributed to several methodological factors biasing the rate of ageing of aerobic power. In the first place, differences may be consequence of the type of research design. Many of the studies reported in this paper have been based on cross-sectional comparisons between younger and older adults. The reasons for using these designs are clear: they have financial, time-saving and organizational advantages. However, the use of cross-sectional data in order to obtain greater insight into the processes of intra-individual ageing is problematic [120]. One of the major problems in these studies is the

Table 2 Changes in $\dot{V}O_{2max}$ with advancing age as reported in cross-sectional and longitudinal studies for men and women (for several studies, rate of change was obtained by calculating regression lines after reported data) (*C* cross-sectional, *L* longitudinal)

Study	Population	Study design (C/L)	Follow-up (years)	Change in $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1} \cdot year^{-1}$)
Men and women				
Hossack and Bruce [40]	"Sedentary" population (98 men, age 20–73 years)	C	–	– 0.46
	(104 women, age 20–70 years	C	–	– 0.33)
Posner et al. [85]	"Healthy" population (68 men, age 20–89 years)	C	–	– 0.34
	(104 women, age 20–89 years)	C	–	– 0.26
Fleg and Lakatta [32]	"Healthy" population (83 men, age 28–87 years)	C	–	– 0.39
	(101 women, age 22–82 years	C	–	– 0.25
Vaitkevicius et al. [109]	"Sedentary" population (96 men, age 21–91 years)	C	–	– 0.25
	(50 women, age 26–96 years)	C	–	– 0.40
Åstrand et al. [7]	Physical education students (31 men, age at final measurement 41–54)	L	21.0	– 0.64
	(35 women, age at final measurement 41–46)	L	21.0	– 0.44
Shvartz and Reibold [97]	Rewiew of 62 studies (61 cross-sectional, 1 longitudinal, age 6–75) (all men)	C/L (one study)	19.0	– 0.40
	(all women)	C	–	– 0.40
Men				
Robinson [90]	"Normal" non-athletic population ($n = 81$, age 6–76 years)	C	–	– 0.42
McDonough et al. [65]	"Healthy" population ($n = 86$, age 40–69 years)	C	–	– 0.30 (between age 40–59)
				– 0.80 (between age 60–69)
Aunola and Rusko [11]	"Healthy" population ($n = 33$, age 20–50 years)	C	–	– 0.41
Vogel et al. [118]	Untrained U.S. Army personnel ($n = 702$, age ± 17–55 years)	C	–	– 0.50
Quirion et al. [88]	University professors and assistants ($n = 72$, age 25–60 years)	C	–	– 0.50
Fuchi et al. [35]	Long-distance runners ($n = 55$, age 30–80 years)	C	–	– 0.44
Jackson et al. [46]	"Healthy" population of employees ($n = 1604$, age 25–70 years)	C	–	– 0.48
Poehlman et al. [84]	"Healthy" population ($n = 300$, age 17–78 years)	C	–	– 0.43
Dehn and Bruce [27]	"Healthy" population ($n = 700$, age 6.7–81.3 years)	C	–	– 0.40
	"Healthy" population ($n = 86$, age 40–72 years)	C	–	– 0.28
	–Sample from same population ($n = 40$)	L	2.3	– 0.94
	–"Active" ($n = 24$)	L	2.3	– 0.56
	–"Inactive" ($n = 8$)	L	2.3	– 1.62
Irving et al. [45]	"Healthy active and sedentary" population ($n = 12$, age at final measurement 62.3 ± 7.1 years)	L	8	– 0.85
	–"Active" ($n = 6$, age at final measurement 63.7 ± 5.6 years)	L	8	– 0.79
	–"Inactive" ($n = 6$, age at final measurement 61.0 ± 8.8 years)	L	8	– 0.96
Women				
Åstrand [6]	"Active population" ($n = 44$, age 20–65 years)	C	–	– 0.39
Atomi and Miyashita [10]	"Sedentary" population ($n = 102$, age 20–62 years)	C	–	– 0.28
	"Active population" ($n = 46$, age 20–62 years)	C	–	– 0.32
Ilmarinen et al. [42]	Municipal employees ($n = 35$ women, age at final measurement 54.8 ± 3.6 years)	L	3.6	– 0.58
Plowman et al. [83]	"General" population ($n = 34$, age at final measurement 21–73 years)	L	3.5–9.0	– 0.32

possible existence of differences between cohorts, which are reflected in historical differences, e.g. in working conditions, diseases during youth, nutrition, socio-economic status and environmental factors. Another overall major concern in cross-sectional ageing research is the representativity of the elderly samples, especially in studies including exercise tests. For instance, the presence of a high proportion of subjects with clinically manifest diseases may result in bias of the true rate of normal ageing. However, as a high proportion of elderly humans suffer from a disease, it may be claimed that age-dependent diseases and disorders, such as coronary artery disease, are part of the normal ageing process [18]. In general we can say that the proportion of a population volunteering for physical testing is attenuated in the older age groups, partly because of medical rejections and partly because caution in physical performance testing increases with age. In addition to this, often the health-conscious and physically fit members of an older population tend to volunteer for this kind of study, also leading to an underestimation of the true rate of ageing [94]. Taken together, cross-sectional changes in aerobic capacity with age are generally found to be smaller than those reported by longitudinal studies.

In the second place, reported differences between studies may be the result of variation in the research methodology applied, such as directly measured versus predictive submaximal assessed $\dot{V}O_{2max}$. In a study comparing both methods, significant differences in results have been reported [53] regarding the validity of predictive tests [115]. Comparable studies have also shown that the exercise protocol [66] or the type of maximal exercise applied influences $\dot{V}O_{2max}$ [55]; for instance, lower maximal values were obtained with a cycle ergometer and step test than with treadmill running.

When testing older subjects, the outcome of maximal physical exercise testing may also be biased as the person tested is often reluctant to exert himself maximally [94]. This may be attributed to dyspnoea, fear for medical complications, muscular weakness, the appearance of electrocardiographic abnormalities [96] or inexperience with physical exercise at maximal effort. Finally, differences in characteristics of the samples, such as age ranges, prevalence of diseases, differences in body weight and body composition, and physically active versus sedentary life-style are supposed to affect the rate of decline in $\dot{V}O_{2max}$ to a certain degree. Buskirk and Hodgson [21] even hypothesized that the rate of decline in $\dot{V}O_{2max}$ with age is not linear, as suggested before, but curvilinear (Fig. 2), representing different acceleration patterns between segments of the life span which are greatly influenced by changes in body weight and regular exercise and segments characterized by sedentary living. The results of multiple regression analyses reported by Jackson et al. [46] support this hypothesis by indicating that in addition to age, percent

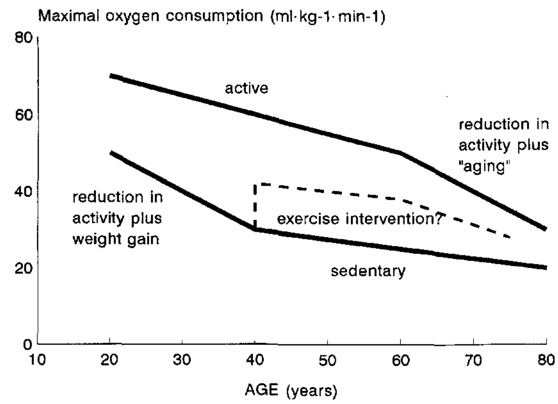

Fig. 2 Possible inter-individual differences in the age-related decline in maximal oxygen consumption. The possible effects of regular physical activity (or lack thereof) and the decline at advanced age are depicted [21]

body fat and self-reported physical activity and their interaction accounted for additional $\dot{V}O_{2max}$ variance.

In contrast to these variations in absolute values, a more consistent picture can be obtained by expressing the rate of decline of $\dot{V}O_{2max}$ in values relative to the highest $\dot{V}O_{2max}$ during life. In general, this peak level is reached at the age of 20–25 years [8, 97]. When translated into relative declines, a majority of the studies in Table 2 were found to report a steady decrease between 7% and 10% per decade from age 20–25 years onwards for both men and women. At the retirement age of 65 years, $\dot{V}O_{2max}$ is reduced to 60%–70% of the average value at age 25 years in both male and female workers. The absolute maximal values for women appear to be less than for men within all age groups [8, 97]. However, large inter-individual variations have been reported [42] in absolute as well as relative declines, portraying ageing workers as a heterogeneous group regarding aerobic capacity.

Muscular capacity

In addition to deterioration in aerobic capacity, decreased muscular performance is certainly one of the clearest characteristics of physical ageing. Slowness of movement and weakness are commonly attributed to ageing of skeletal muscles [64]. The first scientific research on age-related changes in muscle capacity was in fact performed as long ago as the beginning of the last century [87], exhibiting a 40% loss of maximal muscle force by the age of 65 years. Among more recent material, a distinction can be made between studies concentrating on the age group of 65 years upwards only [2, 13] and studies focusing on the age ranges equivalent to the working population. In this section, emphasis will be placed on the latter studies.

Muscular capacity in humans is characterized by muscle strength, muscle contraction speed and muscle endurance. A majority of the ageing-muscle studies have focussed on deterioration of muscle strength only. A fair comparison of these studies by listing in a table is problematic as the inter-study differences in methodology are considerable. Methodological choices, for example the type of test employed, isometric versus isokinetic, and the type of muscle groups examined are suggested to influence the outcome of these studies [101]. Although muscle strength tends to be better preserved than aerobic capacity, numerous investigations on age-related changes in isometric and isokinetic muscular strength have reported a decline with age [29, 30, 34, 52, 59, 61, 74, 102, 107, 123].

The comprehensive and classical study of Asmussen and Heebøll-Nielsen [4] reported an increase in overall isometric strength of 25 different muscle groups from age 20–22 (100%) years to age 30 (104%) years for men (Fig. 3). After this, an accelerated decrease took place to 90% at age 60 years. For women, a constant strength was found between age 20 and 40 years (80% of men at age 20–22 years) which was followed by an accelerated decline to 54% of the isometric strength of men in the 55-year age group (Fig. 3). In accordance with this study, curvilinear patterns – increases into the third or fourth decade, a small decline into the fifth or sixth decade and an accelerating decline there after – have been reported for both isometric and isokinetic strength of muscle groups in several cross-sectional and longitudinal studies [51, 60, 116].

In general, large differences in strength-age relationships can be found between muscle groups and also between men and women. For instance for muscle groups, differences can be observed in the age at which the highest peak strength level is achieved during life, as well as in the starting point of an age-related decline. Characteristic differences in this respect have been reported between the muscles of the upper extremities and those of the lower extremities. The muscles of the upper extremities appear to exhibit highest isometric peak strength levels at an earlier age than do those of the lower extremities [4, 15]. Viitalso et al. [116] also observed a greater rate of decline with age for the lower extremities (knee-extension strength) compared with the muscle groups of the upper extremities (trunk flexion and extension and elbow flexion strengths). It has been argued that these differences are probably due to an age-related decline in activity of the legs in explosive physical activities such as running and jumping, as opposed to the continued use of arms and hands in daily life activities [4, 15].

In addition to muscle strength, muscle contraction speed is also found to slow down with increasing age [72, 81], indicating a prolonged time to peak tension of muscle force in the elderly. A study by Larsson et al. [60] reported an almost identical pattern in decline of maximal knee extension velocity with age as compared with maximal isometric and isokinetic strength. When correcting for the decrease in maximal strength, the less well documented voluntary isometric and isokinetic endurance seems to be unaffected in older individuals [61]. In accordance with these studies, Petrofsky and Lind [82] reported no changes in duration of a fatiguing handgrip contraction at a tension of 40% of maximal voluntary contraction (MVC) with advancing age. Laforest et al. [59] and Nakao et al. [71] observed the same findings for endurance of the knee extensors.

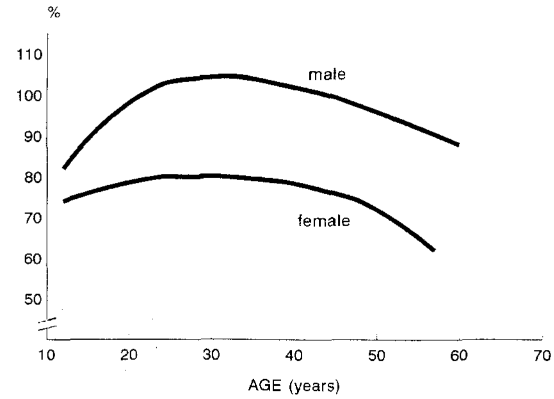

Fig. 3 Mean isometric strength of 25 different muscle groups in percent of strength of 20- to 22-year-old men (100%) in relation to age for both males and females [4]

From the above results it may be concluded that the overall decline in muscular capacity up to the age of 65 years seems to be less marked as compared with aerobic capacity. Depending on the muscle group, a decline in muscle strength of 10%–25% at age 65 (expressed as a percentage of the highest peak value during life) is reported for both sexes. However, as reported for aerobic capacity, there is evidence of large inter-individual variation in muscular capacity in all age groups [51]. This variation may be attributed to differences in physical activity during leisure time [29, 59] and body mass [116] as the lifting of extra body weight is assumed to have a beneficial training effect on the muscle groups of the lower extremities in particular.

Physical workload and ageing

In order to assess the effects of an age-related decline in physical work capacity on the balance between physical workload and physical work capacity, insight into the remaining concepts which may be regarded as determinants of the physical workload is needed.

Figure 4 visualizes the impact of ageing on the relation between physical work demands on the one hand and physical work capacity on the other. This figure of Ilmarinen et al. [44] illustrates an age-related decrease in physical work capacity in relation to similar work demands for younger and older workers. The

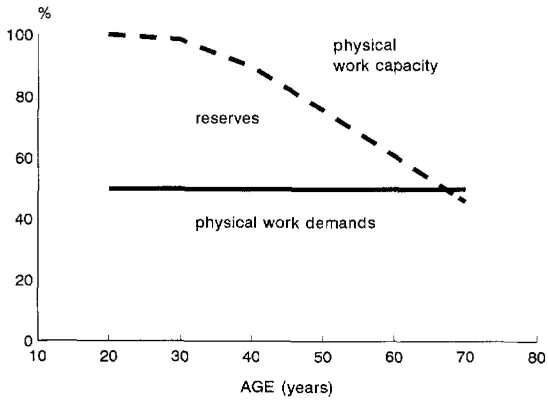

Fig. 4 Relation between physical work capacity and physical work demands with age [44]

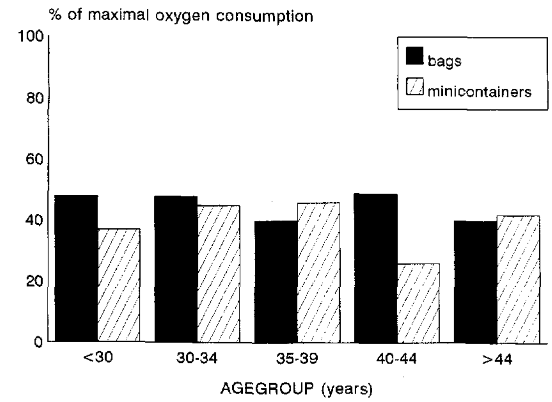

Fig. 5 Percentage of the maximal oxygen uptake during the task loading for two collecting methods: bags ($n = 51$) and mini containers ($n = 47$) with age [33]

discrepancy between a diminishing capacity and stable work demands contributes significantly to a reduction in reserve capacity of the ageing worker.

Quite recently several studies have been carried out to assess differences in physical work demands for younger and older employees within occupations. Between the various age groups, no systematic differences in work demands were reported among construction workers, vehicle inspectors and firefighters [39, 62, 68]. However, the variables as well as the validity of the methods used for assessing work demands still remain a source of discussion [110], raising the need for additional research.

From results of cross-sectional and longitudinal laboratory studies it is clear that in general the absolute oxygen consumption, $\dot{V}O_2$, at fixed submaximal work demands remains at the same level with advancing age and is independent of the individual $\dot{V}O_{2max}$ [6, 7, 14, 49, 90, 92]. Therefore, variation between age groups in the absolute $\dot{V}O_2$ during work is not expected when the work demands are at the same level. Field studies comparing absolute values of $\dot{V}O_2$ between younger and older workers within occupations are scarce and have reported different results. Ilmarinen and Rutenfranz [43] examined 120 men, 23–60 years old, in six different types of occupation. Within each work group the mean absolute $\dot{V}O_2$ during the workday was found to be at the same level for all age groups. In contrast, Hagen et al. [37] observed a significantly lower absolute $\dot{V}O_2$ for older lumberjacks for all working phases compared with their younger colleagues.

Relative aerobic workload can be expressed by the $\dot{V}O_2$ as a percentage of the maximal aerobic capacity ($\dot{V}O_{2max}$), representing the balance between physical workload and physical work capacity. As a consequence of a declining $\dot{V}O_{2max}$ and stable work demands during work, as visualized in Fig. 4, it is suggested that for the ageing worker the relative $\dot{V}O_2$ will increase with growing age. In the previously mentioned study of Ilmarinen and Rutenfranz [43] an increase in this relative $\dot{V}O_2$ with advancing age was reported within groups carrying out physical work mainly. After the age of 50 years, the relative $\dot{V}O_2$ of non-motorized mail carriers was also found to increase systematically [75]. On the other hand, in a recent field study on aerobic workload among a group of refuse collectors [33], with normal age-related differences in $\dot{V}O_{2max}$, it was revealed that the relative $\dot{V}O_2$ did not change significantly with age as might have been expected (Fig. 5). The authors hypothesized that this might have been the result of a lower working rate or higher work efficiency among the group of older refuse collectors.

This latter hypothesis suggests that the actual working method, too, must be considered as a determinant of the individual workload (Fig. 1). Within occupations with fairly comparable work demands for all workers, individual differences in actual working method may finally result in variation in the working posture [20, 56]. In addition to working posture, it is conceivable that these individual differences in actual working method may also be responsible for inter-individual variation in workers' movements and exerted forces, resulting in variation in the actual physical workload. In order to achieve an acceptable physical workload it might be hypothesized that for the ageing worker a decline in the individual physical work capacity in relation to stable physical work demands first stimulates an alteration in the actual working method applied. Possibilities of bringing about changes in the actual working method, such as use of (mechanical) devices or slowing of work pace, largely depend on the decision latitude permitted in the working situation. In addition to decision latitude, physical work capacity, for instance physiological capacities and physical skills, but also knowledge, experience and motivation must be considered as meaningful determinants of the actual working method.

Long-term physical health effects

In spite of progressive mechanization in many production processes, extremely high aerobic workloads are still reported among older workers [33, 43, 75, 103]. In many individual cases the permissible upper tolerance limit of 30%–35% of the relative $\dot{V}O_2$ for prolonged physical work over an 8-h work day [48] is amply exceeded, indicating an imbalance between the physical workload and the physical work capacity. A high relative $\dot{V}O_2$ refers to low reserve capacity insufficient for the recovery of short-term physiological responses to work before the beginning of the next work day [44]. With increasing age, a slowed recovery of physiological variables directly after exercise [22, 57, 69, 90, 122] and prolonged physical after-effects following a workday are often reported. For instance, only for a group of older shiftworkers did De Zwart et al. [25] observed a significant decline in performance on a physical exercise test compared with a baseline value 1 day after working seven consecutive night shifts in a physically demanding occupation.

Muscle activity can result in the onset of short-term local muscle fatigue. In the case of isometric contractions, for example, the onset of fatigue occurs more rapidly when the relative force exerted crosses a relative threshold of the MVC [50]. When MVC decreases with age the "fatigue threshold" is expected to decline for the ageing worker, influencing the time and frequency with which this specific threshold is exceeded during daily work. For levels of MVC above 40%, Deep and Drury [26] reported significantly higher values of perceived exertion on sustained isometric contractions for the older age group, 50–59 years, compared with the younger age group of 20–29 years.

When a muscle is fatigued repeatedly without sufficient recovery after a work day, complaints of long-term or chronic fatigue may arise. A widely held hypothesis is that this chronic fatigue, in the absence of adequate recovery, can cause or aggravate the development of musculoskeletal disorders [3, 99]. Until now, however, the precise mechanism involved has been poorly understood. For the ageing worker, a lowered "fatigue threshold" in combination with a reduced recovery after muscle activity with age is suggested to induce chronic "overload" of muscles and tendons. Daily overload for many years, in which accumulation of minor local muscle damage and muscle changes in combination with an age-related deterioration is expected, might be suggested as the main factor underlying an increase in work-related musculoskeletal complaints with age, as has been frequently reported in epidemiological studies [28, 105, 108, 111]. Finally, these long-term effects can impair capacities to a level at which continuation of the work career is endangered. Disablement as a possible consequence of these long-term physical health effects is found to be one of the main factors responsible for involuntary drop-out for older workers in industrialized countries before attainment of the retirement age [106].

Concluding remarks

The conceptual model of "ageing and physical workload" emphasizes the complexity of the study of ageing and physical workload, as described in this paper. In order to obtain greater insight into the impact of ageing on the balance between physical workload and physical work capacity, results from laboratory, field and epidemiological studies from many disciplines have been gathered and arranged by means of the conceptual model.

In spite of various methodological problems and differences, studies summarizing age-related changes in physical work capacity during working life for men and women show consistent findings. Although muscular capacity seems to be better preserved than aerobic capacity, both exhibit progressive declines after the age of 30 years. However, it is clear that there is marked inter-individual variability in physical work capacity within age classes, as well as variability in the rate of change of physiological variables with advancing age [27, 42]. These variations may be attributed to individual differences in biological ageing and in the onset of diseases, both resulting from individual differences in genetic factors [58] and exposure to environmental factors. Moreover, it is evident that differences in lifestyle, such as level of physical activity, also have a large influence on the diversity in individual physical work capacity with age [27, 36, 38, 46].

Mixed findings have been reported in the few studies comparing physical work demands of young and elderly workers within the same occupation. Possible explanations for these inconsistent results include a change in actual working method with advancing age, such as slowing of work rate, interspersal of rest pauses and enhanced efficiency due to long experience of a given task [95], biasing the assessment of physical work demands by means of physiological measurements. We suggest that for the ageing worker the actual working method applied may be considered an important instrument in order to compensate for a declining physical work capacity. However, supporting evidence is still lacking. On the other hand, these conflicting results also may be attributed to selection of older workers with a high physical work capacity, biasing the outcome of the relative workload. This phenomenon of self-selection by the employee as well as selection by the employer on health matters is frequently reported, being better known as the healthy worker effect [24, 117, 121], and has been shown to affect almost every cohort study including workers [67]. Therefore, when studying the ageing worker, as in the present paper, one has to be aware that the elderly working population of "survivors" often appears to be highly selected from a health point of view.

Despite selection effects and coping mechanisms, it is evident that for many ageing workers physical workload still appears high [44], raising the need for preventive measures. Daily physical "overload" for many years, as the outcome of an age-related imbalance between physical work capacity and physical workload, is suggested to result in long-term physical health effects with chronic musculoskeletal complaints as one of the major outcomes. However, our knowledge about the precise factors underlying the onset and development of these complaints with advancing age is still very poor.

Preventive measures to reduce the individual physical workload of the ageing worker should initially focus on several determinants. First, the working situation may be regarded as an appropriate object for measures aimed at reducing physical work demands, for example by ergonomic adaptation of the workplace or expansion of decision latitude. Second, improvement of the actual working method, for instance by learning to apply less harmful lifting techniques and working postures, seems to have beneficial effects on the individual physical workload and related after-effects [56]. Finally, attention should be paid to the age-related decline in the physical work capacity. In contrast with regular dynamic sports exercises, exposure to heavy physical work demands for many years has consistently been reported to have almost no beneficial effects on aerobic capacity [1, 43] or muscular capacity [29, 73, 74, 89]. Therefore, to ensure maintenance of an optimal physical work capacity up till retirement age, varied exercises during leisure should also be recommended for workers in physical occupations.

In conclusion, the study on physical workload and the ageing worker seems to be complex in various ways. The conceptual model of "ageing and physical workload" presented in this paper was found to be suitable for the arrangement of the basic concepts presented in the literature and for discussing the hypothetical relations between these concepts. However, research data required to validate the entire model are still lacking. For instance, extensive longitudinal epidemiological studies are needed concerning the onset and development of long-term physical health effects, such as musculoskeletal complaints, in relation to age and specified physical work demands. Such studies would be valuable in our attempts to counter the ongoing health-related outflow of ageing workers from physically demanding occupations.

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